

Unsteady Turbopump Flow Simulations

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ABSTRACT

The objective of the current effort is two-fold: 1) to provide a computational framework for design and analysis of the entire fuel supply system of a liquid rocket engine; and 2) to provide high-fidelity unsteady turbopump flow analysis capability to support the design of pump sub-systems for advanced space transportation vehicle. Since the space launch systems in the near future are likely to involve liquid propulsion system, increasing the efficiency and reliability of the turbopump components is an important task. To date, computational tools for design/analysis of turbopump flow are based on relatively lower fidelity methods. Unsteady, three-dimensional viscous flow analysis tool involving stationary and rotational components for the entire turbopump assembly has not been available, at least, for real-world engineering applications. Present effort is an attempt to provide this capability so that developers of the vehicle will be able to extract such information as transient flow phenomena for start up, impact of non-uniform inflow, system vibration and impact on the structure. Those quantities are not readily available from simplified design tools.

In this presentation, the progress being made toward complete turbo-pump simulation capability for a liquid rocket engine is reported. Space Shuttle Main Engine (SSME) turbo-pump is used as a test case for the performance evaluation of the hybrid MPI/Open-MP and MLP versions of the INS3D code. Relative motion of the grid system for rotor-stator interaction was obtained by employing overset grid techniques. Time-accuracy of the scheme has been evaluated by using simple test cases. Unsteady computations for SSME turbo-pump, which contains 106 zones with 34.5 Million grid points, are currently underway on Origin 2000 systems at NASA Ames Research Center. Results from these time-accurate simulations with moving boundary capability and the performance of the parallel versions of the code will be presented.



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April 4-5, 2001, Huntsville, AL

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David Taylor Model Basin
"Hydrodynamics Colloquium"
April 12, 2001, Bethesda, MD

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- INTRODUCTION
 - Major Drivers of the Current Work
 - Objectives
- APPROACH / PROGRESS
 - Formulation and Solution Method
 - Computational models
 - Code parallelization
 - Unsteady SSME-rig1 turbopump simulation
- SUMMARY

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Major Drivers of the Current Work



- TOOLS FOR AEROSPACE DESIGN
 - Decrease design cycle time \Rightarrow Rapid turn-around
 - Increase design/process fidelity \Rightarrow High accuracy and low variation
 - Increase discipline integration \Rightarrow Increased range of options via IT

Turbo-pump component analysis \Rightarrow Entire turbo pump simulation

- Computing time requirement is large :
To achieve 1000 times speed up by 2001 over what was possible in 1992.

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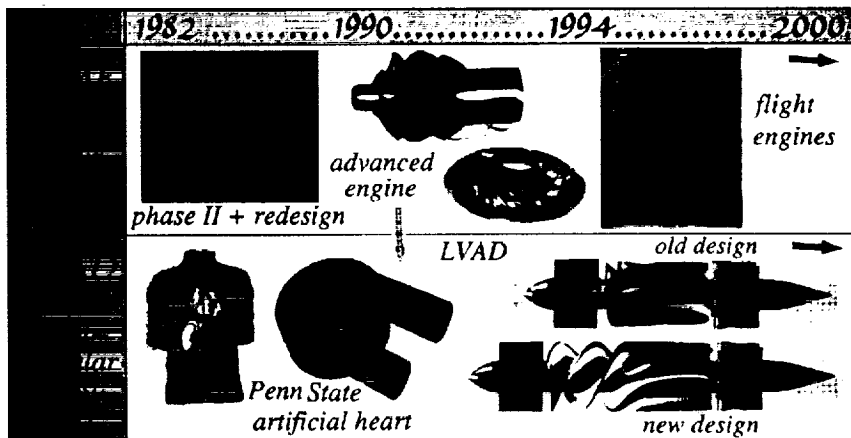


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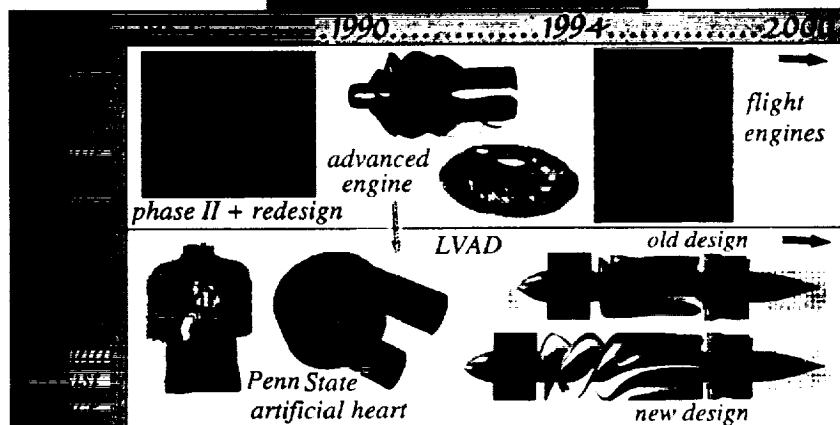
Objectives

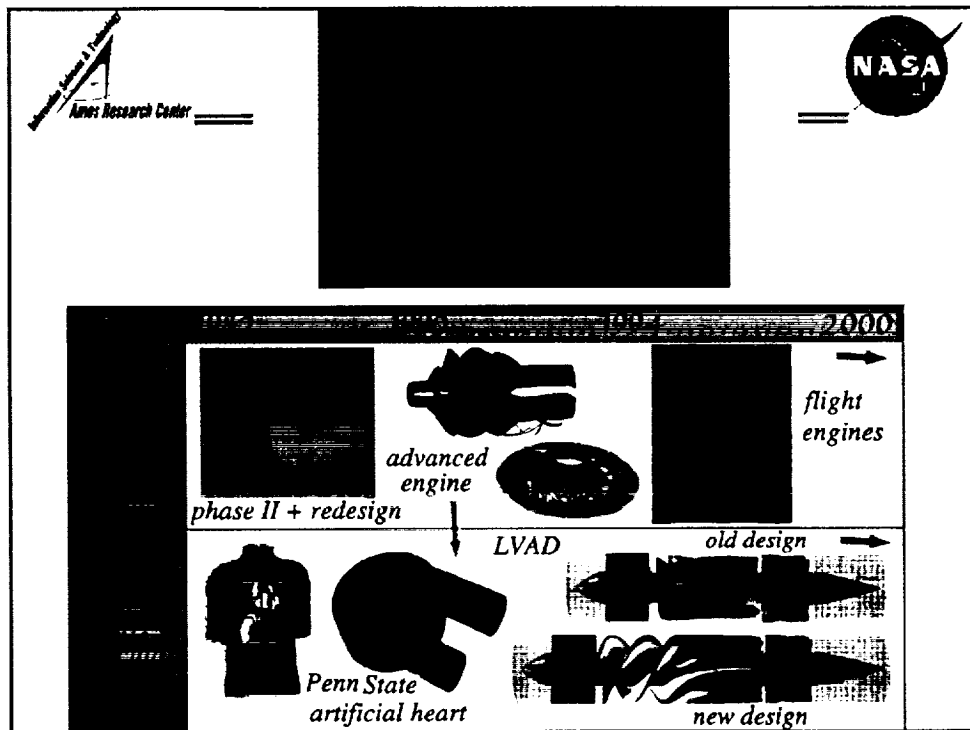


- To enhance incompressible flow simulation capability for developing aerospace vehicle components, especially, unsteady flow phenomena associated with high speed turbo pump.




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Time Accurate Formulation



- Time-integration scheme
 - Artificial Compressibility Formulation
 - Introduce a pseudo-time level and artificial compressibility
 - Iterate the equations in pseudo-time for each time step until incompressibility condition is satisfied.
 - Pressure Projection Method
 - Solve auxiliary velocity field first, then enforce incompressibility condition by solving a Poisson equation for pressure.

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Artificial Compressibility Method



Time-Accurate Formulation

- Discretize the time term in momentum equations using second-order three-point backward-difference formula

$$\left(\frac{\partial U}{\partial \xi} + \frac{\partial V}{\partial \eta} + \frac{\partial W}{\partial \zeta} \right)^{n+1} = 0 \quad \frac{3q^{n+1} - 4q^n + q^{n-1}}{2\Delta t} = -r^{n+1}$$

- Introduce a pseudo-time level and artificial compressibility,
- Iterate the equations in pseudo-time for each time step until incompressibility condition is satisfied.

$$\frac{1}{\Delta \tau} (p^{n+1,m+1} - p^{n+1,m}) = -\beta \nabla q^{n+1,m+1}$$

$$\frac{1.5}{\Delta t} (q^{n+1,m+1} - q^{n+1,m}) = -r^{n+1,m+1} - \frac{3q^{n+1,m} - 4q^n + q^{n-1}}{2\Delta t}$$

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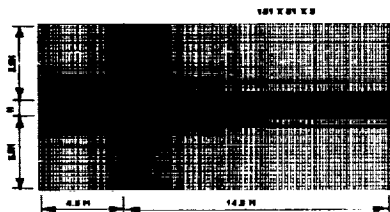
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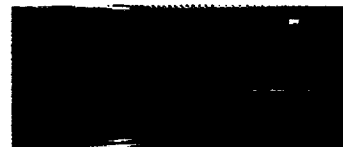
Impulsively Started Flat Plate at 90°



- GRID
Thickness of plate = 0.3H



T=1.2

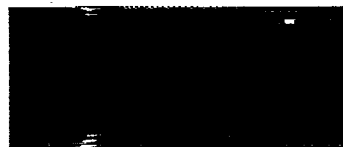


T=2.0



- VELOCITY MAGNITUDE

T=0.4



T=4.0



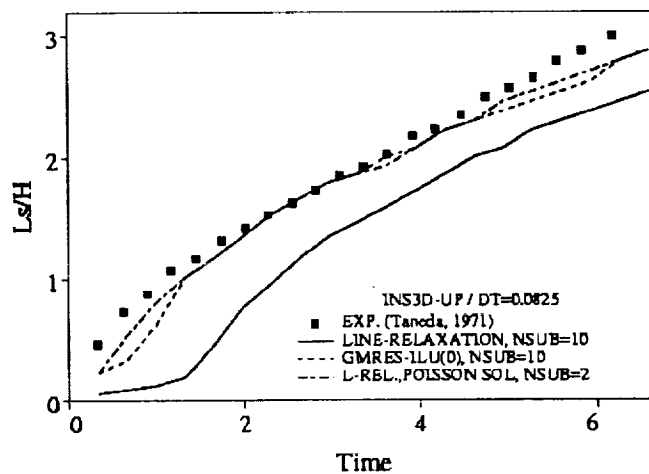
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Impulsively Started Flat Plate at 90°



- Time History of Stagnation Point
- Artificial compressibility incorporated with Poisson solver

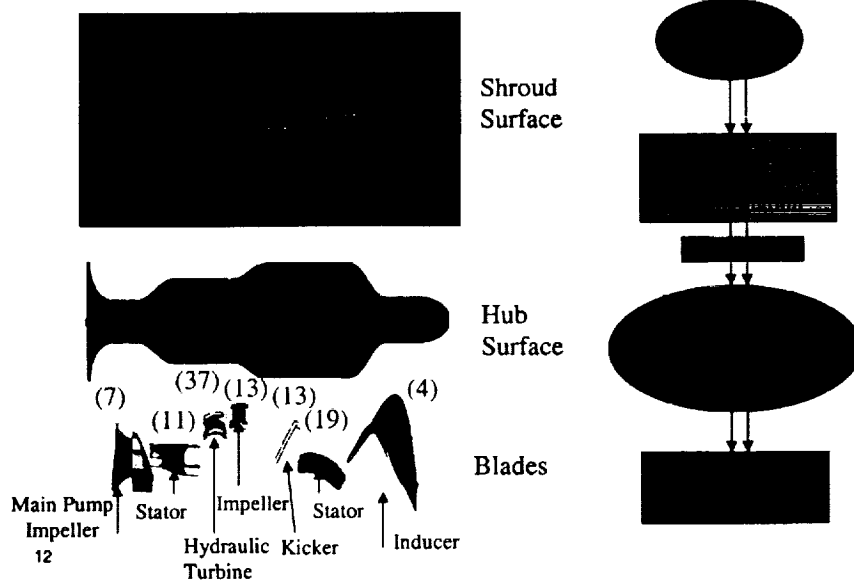


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Boost Pump Computational Model



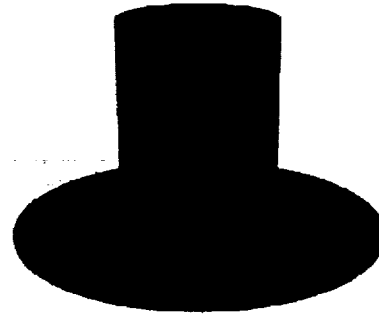
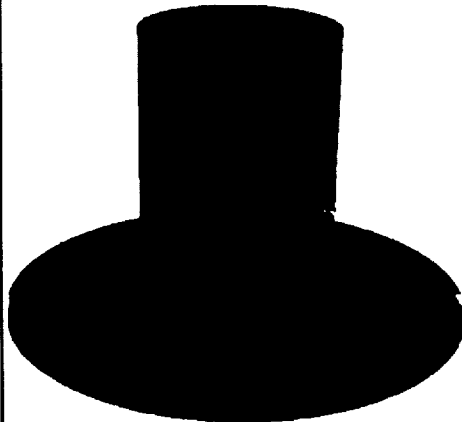


Space Shuttle Main Engine Turbopump



COMPUTATIONAL CHALLENGES :

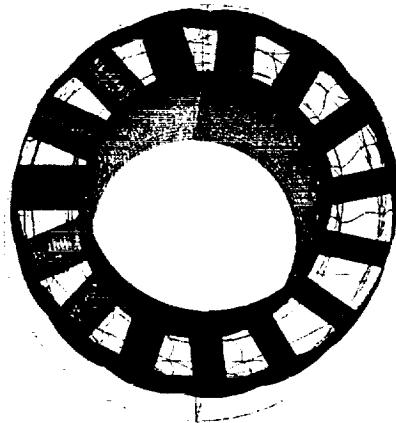
- Cost due to time-accurate flows
- Moving grid system
- Code parallelization



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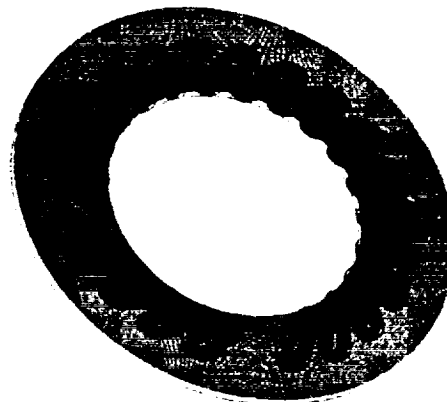


Shuttle Upgrade SSME-rig1



Inlet Guide Vanes

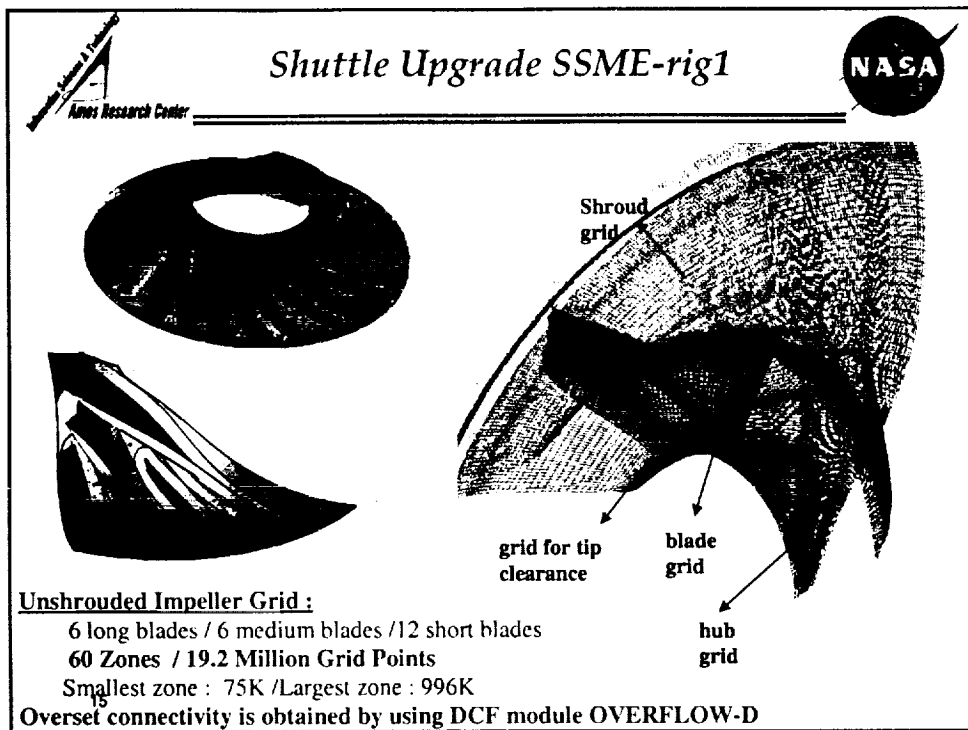
15 Blades
17 Zones / 4.5 M Points



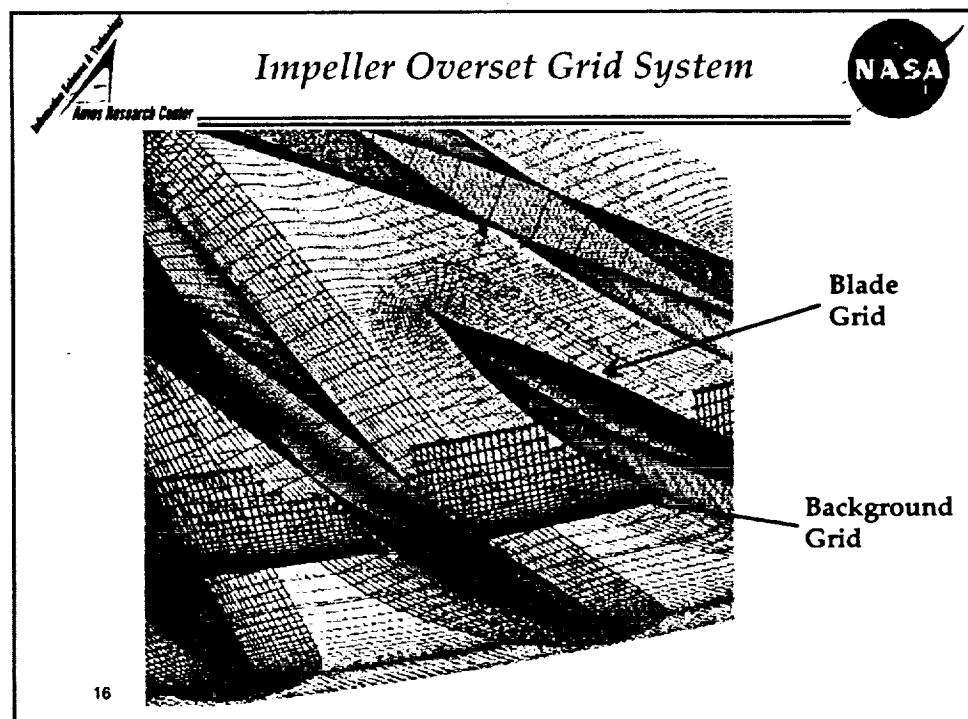
Diffuser

23 Blades
24 Zones / 6.5 M Points

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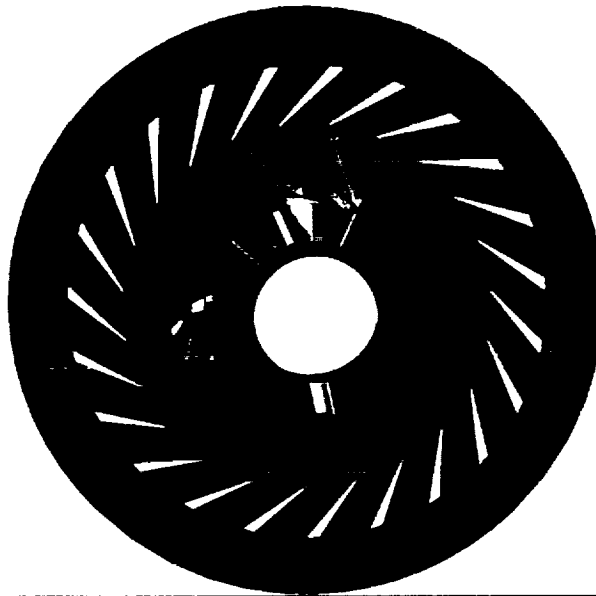


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Shuttle Upgrade SSME-rig1



SSME-rig1

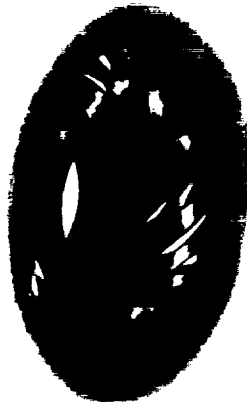
- 114 Zones
- 34.3 Million Points
- 800 physical time steps in one rotation.
- XINTOUT for each position is saved.
- Less than 192 orphan points.



INS3D Parallelization

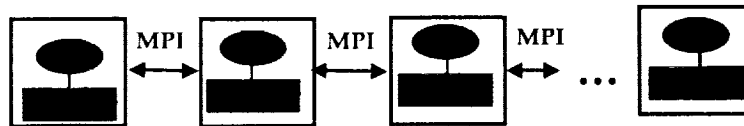
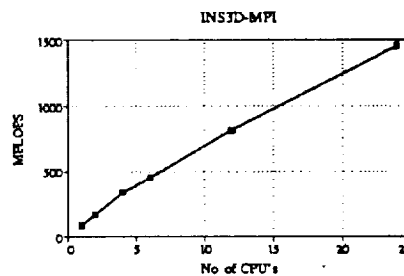


Pressure



INS3D-MPI - coarse grain

Implemented by T. Faulkner & J. Dacles



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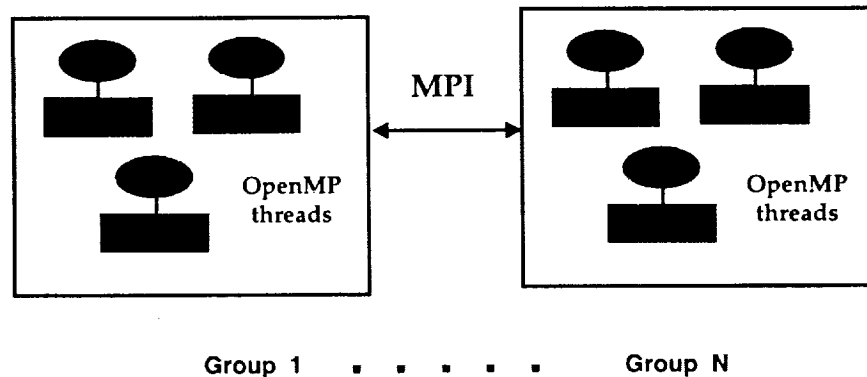
INS3D Parallelization



INS3D-MPI /OpenMP

MPI (coarse grain) + OpenMP (fine grain)

Implemented by using CAPO/CAPT tools - Henry Jin at NASA-Ames



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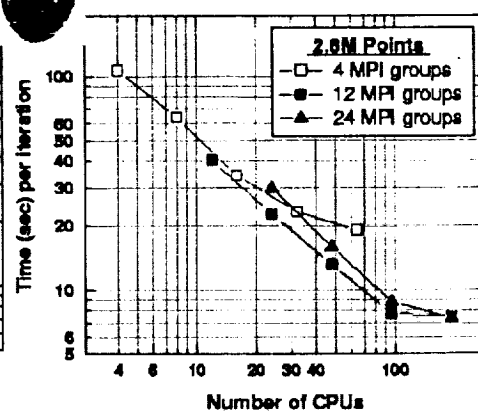
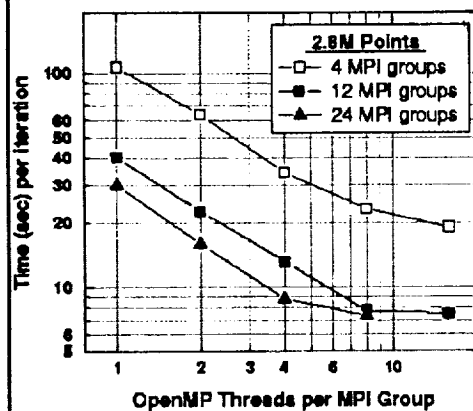


INS3D Parallelization



MPI coarse grain + OpenMP fine grain

TEST CASE : SSME Impeller
24 zones / 2.8 Million points



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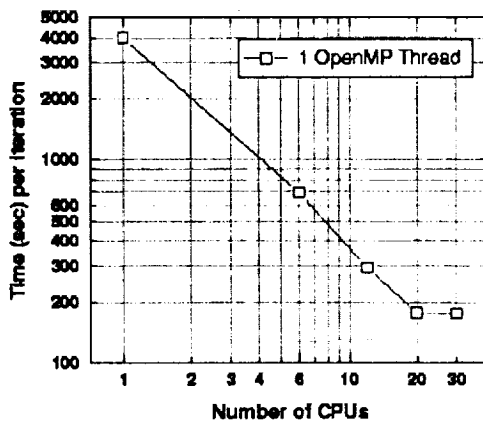
INS3D Parallelization



MPI coarse grain + OpenMP fine grain



TEST CASE : SSME Impeller
60 zones / 19.2 Million points



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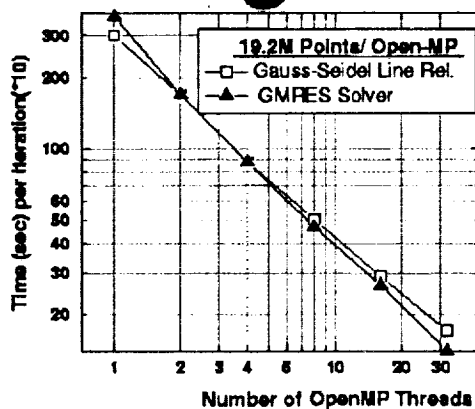
INS3D Parallelization



OpenMP with two different solver



TEST CASE : SSME Impeller
60 zones / 19.2 Million points



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